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(54) **SWARM INTELLIGENCE FOR ELECTRICAL DESIGN SPACE MODELING AND OPTIMIZATION**

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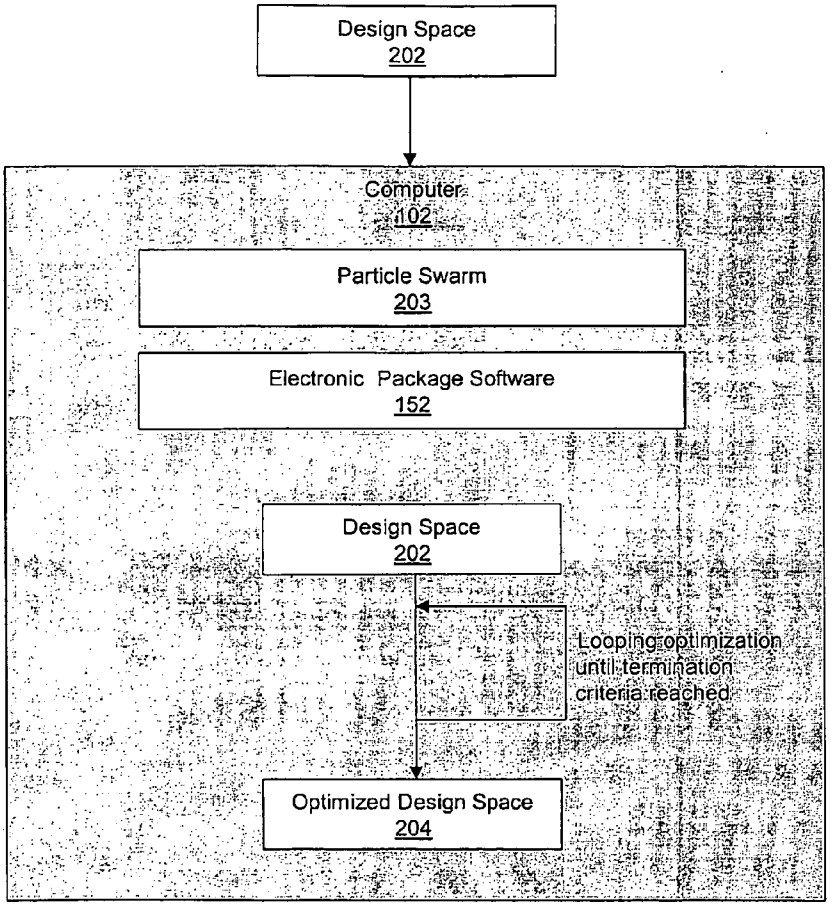
(57) **ABSTRACT**

A method, system, and computer program product for exploring and optimizing an electrical design space. A computer receiving a design space assigns a plurality of initial values (random or predetermined) for optimizing the design space. A particle swarm containing a plurality of particles is created and an optimization of the design space is then performed using the assigned initial values. Following completion of optimization, the global best and personal best for each particle are updated. Velocity vectors and position vectors of the design space are then updated before the computer performs the optimization process again. The process loops, continually updating global and personal bests and velocity and position vectors until a termination criteria is reached. Upon reaching the termination criteria, the best fitness of each particle of the swarm is assigned as an optimized design space. In an alternate embodiment, the particle with the worst target fitness may be assigned.



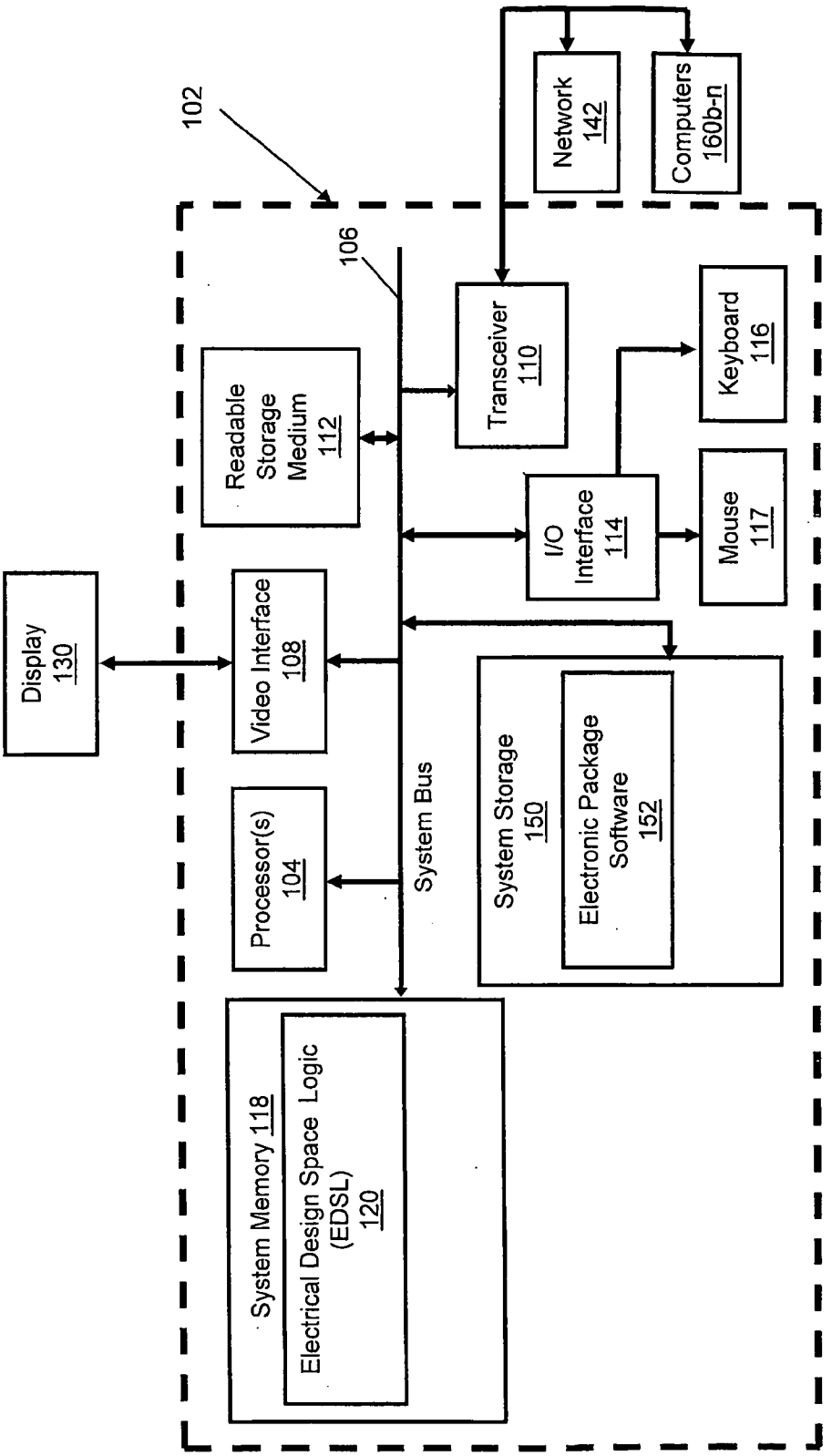

102
106
Network 142
Computers 160b-n
Transceiver 110
Keyboard 116
Readable Storage Medium 112
I/O Interface 114
Mouse 117
Display 130
Video Interface 108
System Storage 150
Electronic Package Software 152
Processor(s) 104
System Bus
System Memory 118
Electrical Design Space Logic (EDSL) 120

FIG. 1

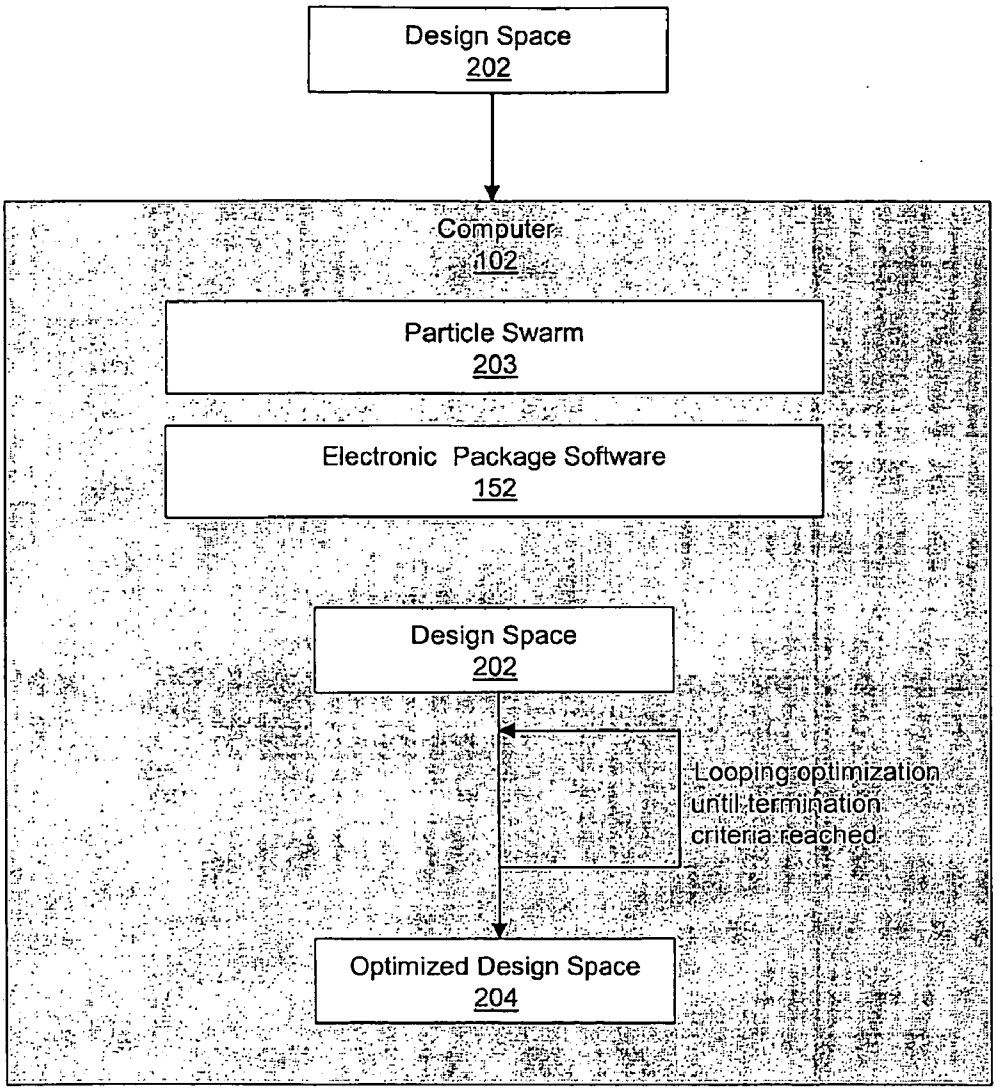

Design Space
202
Computer
102
Particle Swarm
203
Electronic Package Software
152
Design Space
202
Looping optimization
until termination
criteria reached
Optimized Design Space
204

FIG. 2

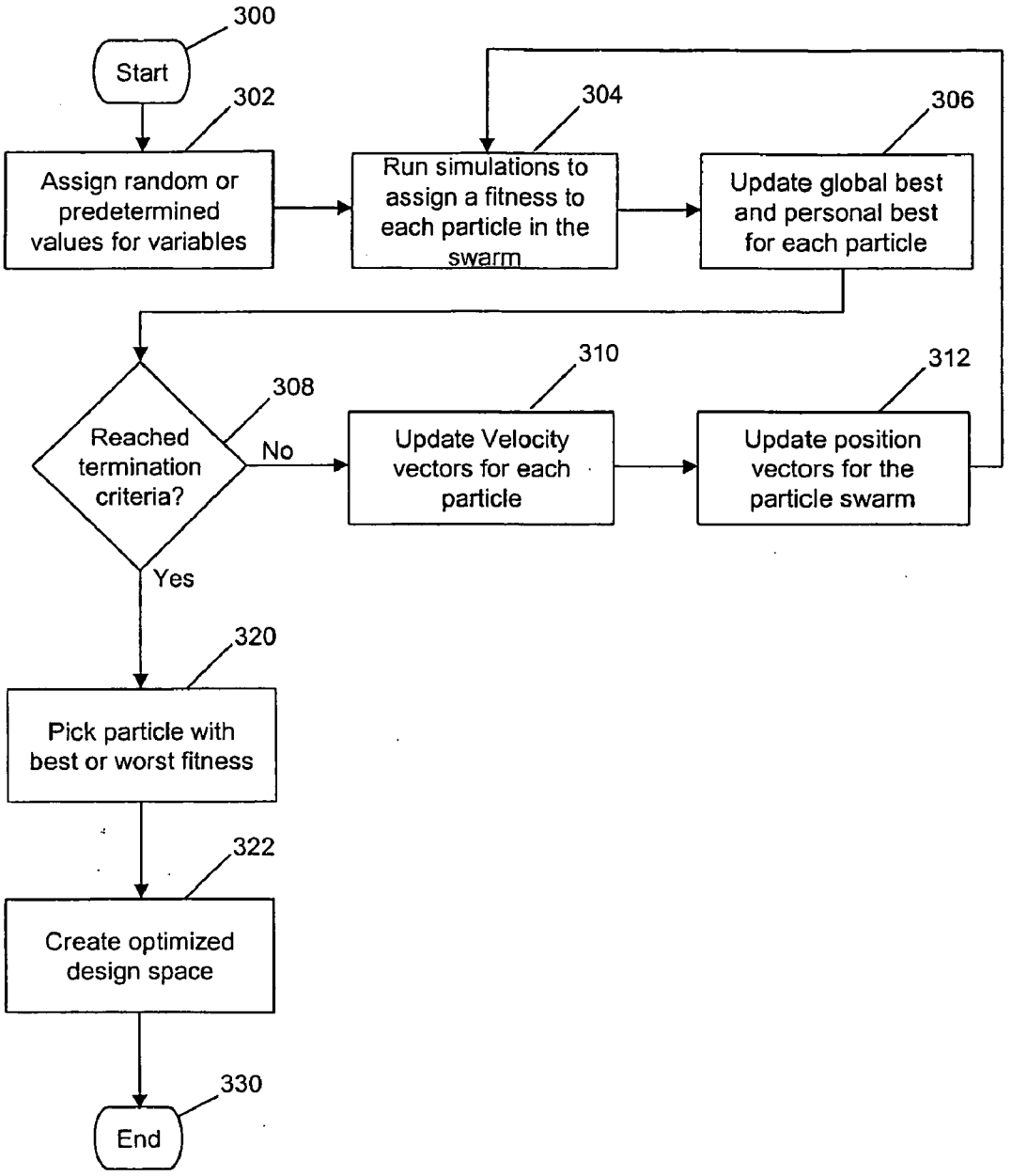

300
Start
302
Assign random or predetermined values for variables
304
Run simulations to assign a fitness to each particle in the swarm
306
Update global best and personal best for each particle
308
Reached termination criteria?
No
310
Update Velocity vectors for each particle
312
Update position vectors for the particle swarm
Yes
320
Pick particle with best or worst fitness
322
Create optimized design space
330
End

FIG. 3

SWARM INTELLIGENCE FOR ELECTRICAL DESIGN SPACE MODELING AND OPTIMIZATION

BACKGROUND OF THE INVENTION

[0001] 1. Technical Field

[0002] The present invention relates in general to computer systems, and in particular to data-processing systems. Still more particularly, the present invention relates to a system for exploring and optimizing an electrical design space using particle swarm intelligence.

[0003] 2. Description of the Related Art

[0004] Designs of today's electronic system have become extremely complex, specifically, the electrical design and verification of complex electronic systems. Electrical design, modeling, simulation, and analysis stages of complex electronic structures, where the number of environmental and manufacturing varying design parameters are extremely high often require a great deal of time or resources of an electronic system. Techniques like Monte Carlo require huge number of simulations in order to achieve a meaningful outcome distribution with a high confidence level. These and similar statistical techniques are not effective to explore highly nonlinear design spaces, which tremendously limits the scope of the application of these statistical approaches.

SUMMARY OF THE INVENTION

[0005] Disclosed is a method, system, and computer program product for exploring and optimizing an electrical design space. A computer receiving a design space assigns a plurality of initial values (random or predetermined) for optimizing the design space. A particle swarm containing a plurality of particles is created and an optimization of the design space is then performed using the assigned initial values. Following completion of optimization, the global best and personal best for each particle are updated. Velocity vectors and position vectors of the design space are then updated before the computer performs the optimization process again. The process loops, continually updating global and personal bests and velocity and position vectors until a termination criteria is reached. Upon reaching the termination criteria, the best fitness of each particle of the swarm is assigned as an optimized design space. In an alternate embodiment, the particle with the worst target fitness may be assigned.

[0006] The above as well as additional objectives, features, and advantages of the present invention will become apparent in the following detailed written description.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] The novel features believed characteristic of the invention are set forth in the appended claims. The invention itself, however, will best be understood by reference to the following detailed descriptions of an illustrative embodiment when read in conjunction with the accompanying drawings, wherein:

[0008] FIG. **1** is a block diagram of a computer in which the present invention may be implemented.

[0009] FIG. **2** is a block diagram of an exemplary system for exploring and optimizing an electrical design space, according to one embodiment.

[0010] FIG. **3** is a high-level logical flowchart of the process for exploring and optimizing an electrical design space, according to one embodiment.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0011] The illustrative embodiments provide a method, system, and computer program product for exploring and optimizing an electrical design space using swarm intelligence, in accordance with one embodiment of the invention.

[0012] In the following detailed description of exemplary embodiments of the invention, specific exemplary embodiments in which the invention may be practiced are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized and that logical, architectural, programmatic, mechanical, electrical and other changes may be made without departing from the spirit or scope of the present invention. The following detailed description is, therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims.

[0013] It is understood that the use of specific component, device and/or parameter names are for example only and not meant to imply any limitations on the invention. The invention may thus be implemented with different nomenclature/terminology utilized to describe the components/devices/parameters herein, without limitation. Each term utilized herein is to be given its broadest interpretation given the context in which that term is utilized.

[0014] With reference now to FIG. **1**, there is depicted a block diagram of a computer **102** in which the present invention may be implemented. Computer **102** includes a processor **104** that is coupled to a system bus **106**. A transceiver **110**, connected to system bus **106**, enables computer **102** to connect to network **142** and computers **160***a-n*, via wired or wireless mechanisms. Video Interface **108**, coupled to system bus **106**, allows for the connection of a Display **130** to computer **102** enabling the view of an electrical design space (including text and graphics) for use by a user of computer **102**. System bus **106** also enables communication with a hardware-based readable storage medium **112** (e.g., Compact Disk-Read Only Memory (CD-ROM), flash drive memory, etc). Input/Output (I/O) Interface **114**, also connected to system bus **106**, permits user interaction with computer **102**, such as data entry via keyboard **116** or mouse **117**.

[0015] Computer **102** also comprises a system storage **124**, which is connected to system bus **106**. System Storage **124** comprises electronic package software **152**.

[0016] Computer **102** also comprises system memory **118**, which is connected to system bus **106**. As shown, system memory **118** also comprises electrical design space logic (EDSL) **120** for exploring and optimizing an electrical design space. EDSL **120** includes code for implementing the processes described in FIGS. **2-3**. In one embodiment, computer **102** is able to utilize EDSL **120** to optimize electrical design space for an electronic package and interconnect subsystem using swarm intelligence, as described in greater detail below in FIGS. **2-3**.

[0017] As illustrated and described herein, computer **102** may be a computer or computing device having the required hardware components and programmed with EDSL **120**, executing on the processor to provide the functionality of the invention. The hardware elements depicted in computer **102** are not intended to be exhaustive, but rather are representative

to highlight essential components required by and/or utilized to implement the present invention. For instance, computer **102** may include alternate memory storage devices such as magnetic cassettes, Digital Versatile Disks (DVDs), Bernoulli cartridges, and the like. These alternate configurations of components and other variations are intended to be within the spirit and scope of the present invention.

[0018] With reference now to FIG. **2**, there is illustrated an exemplary system for exploring and optimizing an electrical design space using particle swarm intelligence, in accordance with one embodiment of the invention. In one embodiment, computer **102** receives a design space **202** for optimization. EDSL **120** assigns a plurality of initial values for each electrical parameter within design space **202**. The initial values may be random or predetermined. Additionally the values may operate within a numerical specific range (e.g., 2.15-3.45). EDSL **120** generates a plurality of particles of a particle swarm **203** and assigns initial velocity vectors for each particle and position vectors for particle swarm **203**. Each particle of the particle swarm is an individual entity which remembers its personal best fit for a target operation from repeated assigned values. A particle may also communicate with other nearby particles to assist in determining a personal or global best. Each particle may represent a value corresponding to a particular entity within the design space. The best fitness for a particular particle is the value, or range of values, for which that particle accomplishes an assigned task. EDSL **120** may then perform an optimization of design space **202** using the initial values by running a simulation (e.g., Hspice® Simulation). During the simulation, EDSL **120** calculates a fitness value for each particle of particle swarm **203** from the assigned initial values. Using the resultant fitness values of the simulation, the global best data for the particle swarm and personal best data for each individual particle of particle swarm **203** are updated. The global best fitness includes best fitness of the each individual particle, or of the swarm of particles as a whole. After each optimization loop, EDSL **120** determines if a termination criteria has been reached. When the termination criteria has not been reached the velocity vectors for each particle and position vectors for particle swarm **203** are updated with new values, and the optimization process is performed again. An optimization process may be limited to a certain termination criteria (e.g., running an optimization a predetermined amount of times, for predetermined variables only). The process may continue for the assigned values for the variables within design space **202**, until the termination criteria has been reached. Based on the fitness value, the global best of particle swarm **203** and particle best of each particle is stored on Computer **102**.

[0019] Upon reaching the termination criteria, an optimized design space **204** is created using an optimized fitness. The optimized fitness incorporates the best fitness values of the velocity vectors for each particle and the best fitness values of the position vectors of particle swarm **203**. In an alternate embodiment, worst fitness values for each particle and the particle swarm **203** may also be used.

[0020] With reference now to FIG. **3**, there is provided a high-level flow chart of an exemplary method for exploring and optimizing an electrical design space using swarm intelligence, in accordance with one embodiment of the invention. After initiator block **300**, initial values (random or predetermined) are assigned for the variables in the electrical space, and for velocity vectors for each particle and for position vectors for particle swarm **203** (block **302**). An optimization simulation is then performed to assign a best fitness is to each particle in the particle swarm (block **304**). The global best for the swarm and a personal best for each individual particle is then updated after each optimization (block **306**). A determination is then made whether a termination criteria for optimization simulations has been reached (block **308**). If the termination criteria has not been reached, EDSL selects a next set of values representing next values for each electrical parameter within the design space, and according to a specified numerical range, for the velocity vectors for each particle for running a next optimization simulation (block **310**). The position vectors for each particle are also updated with new values (block **312**). The process then loops back to block **304** and a next optimization is performed.

[0021] When the termination criteria has been reached, the best (or worst) fitness velocity vector for each particle and best (or worst) fitness position vector for the particle swarm are selected and assigned as optimized values within the design space (block **320**). The design space is then assigned as an optimized design space incorporating the calculated best fitness values from the optimized values calculated during the optimization simulations (block **322**). The process then ends at terminator block **330**.

[0022] In the flow charts above, one or more of the methods are embodied such that a series of steps are performed when the computer readable code is executed on a computing device. In some implementations, certain steps of the methods are combined, performed simultaneously or in a different order, or perhaps omitted, without deviating from the spirit and scope of the invention. Thus, while the method steps are described and illustrated in a particular sequence, use of a specific sequence of steps is not meant to imply any limitations on the invention. Changes may be made with regards to the sequence of steps without departing from the spirit or scope of the present invention. Use of a particular sequence is therefore, not to be taken in a limiting sense, and the scope of the present invention is defined only by the appended claims.

[0023] Although aspects of the present invention have been described with respect to a computer processor and program application/logic, it should be understood that at least some aspects of the present invention may alternatively be implemented as a program product for use with a data storage system or computer system. Programs defining functions of the present invention can be delivered to a data storage system or computer system via a variety of signal-bearing media, which include, without limitation, non-writable storage media (e.g. CD-ROM), writable storage media (e.g. network attached storages, hard disk drive, read/write CD-ROM, optical media), and communication media, such as computer and telephone networks including Ethernet. It should be understood, therefore, that such signal-bearing media, when carrying or encoding computer readable instructions that direct method functions of the present invention, represent alternative embodiments of the present invention. Further, it is understood that the present invention may be implemented by a system having means in the form of hardware, software, or a combination of software and hardware as described herein or their equivalent. Additionally, the present invention may be implemented in a machine in the form of a computer-readable storage medium having a plurality of instructions embodied executing on a processing device.

[0024] Having thus described the invention of the present application in detail and by reference to illustrative embodiments thereof, it will be apparent that modifications and

variations are possible without departing from the scope of the invention defined in the appended claims. In addition, many modifications may be made to adapt a particular system, device or component thereof to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to the particular embodiments disclosed for carrying out this invention, but that the invention will include all embodiments falling within the scope of the appended claims. Moreover, the use of the terms first, second, etc. do not denote any order or importance, but rather the terms first, second, etc. are used to distinguish one element from another.

What is claimed is:

1. A method for exploring and optimizing an electrical design space, the method comprising:
- a computer receiving a design space;
- generating a plurality of particles of a particle swarm, wherein the particle swarm includes an initial position vector;
- assigning a plurality of initial values for each electrical parameter of the design space, wherein the initial values include an initial velocity vector value for each particle;
- calculating a fitness for each particle of the particle swarm;
- performing an optimization of the design space using the plurality of initial values and the calculated fitness for each particle of the particle swarm;
- in response to the completion of the optimization of the design space:
  - updating a global best value for the particle swarm based on the calculated fitness,
  - updating a personal best value for each particle based on the fitness, and
  - determining if the optimization has reached a termination criteria;
- in response to determining that a termination criteria has been reached, creating an optimized design space using an optimized fitness incorporating the global best value for the particle swarm and the personal best value for each particle of the particle swarm.

2. The method of claim **1**, further comprising, in response to determining that the optimization has not reached the termination criteria:
- selecting a next velocity vector for each particle;
- selecting a next plurality of position vectors for the particle swarm;
- performing a next optimization of the design space using the next velocity vector for each particle and the next position vectors for the particle swarm; and
- in response to the completion of the next optimization of the design space:
  - updating the global best value for the particle swarm based on the calculated fitness, and
  - updating the personal best value for each particle based on the fitness.

3. The method of claim **1**, wherein the optimized fitness includes a global worst value for the particle swarm and a personal worst value for each particle of the particle swarm.

4. A computer comprising:
- a processor;
- a memory coupled to the processor;
- processing logic executing on the processor performing the steps of:
  - receiving a design space;
  - generating a plurality of particles of a particle swarm, wherein the particle swarm includes an initial position vector;
  - assigning a plurality of initial values for each electrical parameter of the design space, wherein the initial values include an initial velocity vector value for each particle;
  - calculating a fitness for each particle of the particle swarm;
  - performing an optimization of the design space using the plurality of initial values and the calculated fitness for each particle of the particle swarm;
  - in response to the completion of the optimization of the design space:
    - updating a global best value for the particle swarm based on the calculated fitness,
    - updating a personal best value for each particle based on the fitness, and
    - determining if the optimization has reached a termination criteria;
  - in response to determining that a termination criteria has been reached, creating an optimized design space using an optimized fitness incorporating the global best value for the particle swarm and the personal best value for each particle of the particle swarm.

5. The computer of claim **4**, the processing logic further comprising, in response to determining that the optimization has not reached the termination criteria:
- selecting a next velocity vector for each particle;
- selecting a next plurality of position vectors for the particle swarm;
- performing a next optimization of the design space using the next velocity vector for each particle and the next position vectors for the particle swarm; and
- in response to the completion of the next optimization of the design space:
  - updating the global best value for the particle swarm based on the calculated fitness, and
  - updating the personal best value for each particle based on the fitness.

6. The computer of claim **4**, wherein the optimized fitness includes a global worst value for the particle swarm and a personal worst value for each particle of the particle swarm.

7. A computer-readable storage medium having a plurality of instructions embodied therein, wherein the plurality of instructions, when executed by a processing device, allows a machine to:
- receive a design space;
- generate a plurality of particles of a particle swarm, wherein the particle swarm includes an initial position vector;
- assign a plurality of initial values for each electrical parameter of the design space, wherein the initial values include an initial velocity vector value for each particle;
- calculate a fitness for each particle of the particle swarm;
- perform an optimization of the design space using the plurality of initial values and the calculated fitness for each particle of the particle swarm;
- in response to the completion of the optimization of the design space:
  - update a global best value for the particle swarm based on the calculated fitness,
  - update a personal best value for each particle based on the fitness, and

determine if the optimization has reached a termination criteria;

in response to determining that a termination criteria has been reached, create an optimized design space using an optimized fitness incorporating the global best value for the particle swarm and the personal best value for each particle of the particle swarm.

8. The computer-readable storage medium of claim **7**, the plurality of instructions further comprising instructions for enabling the machine to, in response to determining that the optimization has not reached the termination criteria:

select a next velocity vector for each particle;

select a next plurality of position vectors for the particle swarm;

perform a next optimization of the design space using the next velocity vector for each particle and the next position vectors for the particle swarm; and

in response to the completion of the next optimization of the design space:

update the global best value for the particle swarm based on the calculated fitness, and

update the personal best value for each particle based on the fitness.

9. The computer-readable storage medium of claim **7**, wherein the optimized fitness includes a global worst value for the particle swarm and a personal worst value for each particle of the particle swarm.

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